

FINAL REPORT
HIGHWAY RUNOFF IN AREAS OF KARST TOPOGRAPHY

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ABSTRACT

Karst terrain is characterized by sinkholes, depressions, caves, and underground drainage, generally underlain by soluble rocks such as limestone and dolomite. Because natural filtration through soil is limited in karst areas, pollutants in highway stormwater runoff can directly infiltrate underground sources of drinking water and environments that are habitats for sensitive species. Although the Virginia Department of Transportation (VDOT) has implemented guidelines for construction projects in karst areas to ameliorate this problem, there has been considerable activity at the state level in recent years concerning the protection of karst groundwater. New regulations or requirements regarding karst area runoff could add significantly to VDOT's construction and maintenance activities. This report summarizes the research and regulations to position VDOT to manage karst topography issues appropriately. Although more studies of karst groundwater contamination are needed, the literature does not currently support the need for more stringent regulatory controls than are already in place.

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INTRODUCTION

The term *karst* refers to a landscape spotted with sinkholes, underlain by caves, and having many springs that discharge into stream valleys. In Virginia, karst terrain generally comprises soluble rocks such as limestone. Karst topography primarily occurs within the Valley and Ridge Physiographic Province of western Virginia and is also found in limited areas in Virginia's Blue Ridge, Piedmont, and Coastal Plain Physiographic Provinces. Because natural filtration through soil is limited in karst areas, stormwater runoff can potentially carry pollutants directly to the groundwater basin. Sinkholes are particularly vulnerable to groundwater contamination because they serve as funnels for runoff, creating a direct surface connection to an aquifer. Underground injection of stormwater runoff, through sinkholes and other karst features, can potentially contaminate aquifers that supply drinking water to public water systems and households. Sinkholes can therefore be direct links to underground sources of drinking water and to environments that are habitats for sensitive species.

The National Pollutant Discharge Elimination System, created by the Clean Water Act of 1977, requires that transportation agencies consider and mitigate for the impacts of highway construction, operation, and maintenance on U.S. waters (U.S. Environmental Protection Agency [EPA], 2003a). In Virginia, the Chesapeake Bay Preservation Act, the Virginia Erosion and Sediment Control Regulations (established by the Virginia Department of Conservation and Recreation [DCR]), and the Virginia Stormwater Management Program require that water quality protection measures be implemented throughout the Commonwealth. These acts and regulations directly affect the Virginia Department of Transportation's (VDOT) highway construction, reporting, and maintenance practices. In the numerous regions of karst topography in Virginia, where groundwater may be the most susceptible to contamination, VDOT is responsible for compliance with additional regulations that are unique to these areas.

As public awareness of the dangers of groundwater contamination grows, the EPA and state agencies are under increasing pressure to ensure the safety of the drinking water supply. The EPA can use its authority under the Safe Drinking Water Act (SDWA) of 1974 to initiate any action to protect public health, to force responsible parties to better define the extent of the contamination, or to remediate the underground sources of drinking water to comply with drinking water standards. Although currently requiring registration for only particular VDOT activities in karst areas, the EPA could add additional controls such as permitting, runoff monitoring, or stormwater treatment.

Changes affecting the imposition of new regulatory controls could add significantly to VDOT's current highway design and maintenance activities. VDOT is responsible for the proper management of highway runoff and for compliance with associated regulatory requirements. Changes affecting programs regulated by the EPA or environmental agencies in Virginia may affect VDOT's reporting requirements, permitting obligations, or best management practices (BMPs) concerning highway runoff in karst features. In addition, human changes in areas of karst hydrology can trigger numerous legal activities, and the risks of lawsuits are particularly high near roads in sinkhole-prone areas (P.E. LaMoreaux and Associates, 1995).

PURPOSE AND SCOPE

The purpose of this report is to provide information that will assist VDOT in determining its position on these environmental issues in the face of any future proposed regulatory controls or actions taken by regulatory authorities through existing regulations. The report is limited to a literature review of research and regulations concerning highway runoff in karst areas. This review can serve as grounds for future decisions concerning whether a full-scale research project on this topic is needed. In addition, this review could potentially serve as a basis for countering any claims made against the Commonwealth for property damage attributable to VDOT's stormwater discharges.

METHODS

This literature review included an evaluation of federal and state regulations concerning the management and reporting requirements of highway runoff in areas of karst topography, particularly as they relate to groundwater, drinking water supplies, and the federal Endangered Species Act (ESA) of 1973. These documents are accessible through the websites of state and federal agencies, including the EPA, the Virginia Department of Health, and the Virginia Department of Environmental Quality (DEQ). The literature review also involved compiling completed research on the effect of highway runoff in karst areas, specifically, on its effect on underground sources of drinking water. Effort was focused on a comprehensive search of the literature specifically addressing the effect of stormwater runoff in karst waters. Because of the abundance of studies on the effects of stormwater runoff to receiving waters in general, this portion of the review was less exhaustive. To review available studies on these topics, the library of the Virginia Transportation Research Council and the Science and Engineering Library of the University of Virginia were searched. Online databases, including those available through the University of Virginia were also searched. These included TRIS, the Transportation Research Board's Research in Progress Database, Ecology Abstracts, Web of Science, and World Cat, among others.

RESULTS

Act and Regulations Pertaining to Karst Aquifers

Groundwater is the source of approximately 80% of the community water systems that provide drinking water in the United States. Groundwater is also supplied through private wells as a source of drinking water. In order to protect these underground sources, the U.S. Congress passed the SDWA in 1974. This act gave the EPA the authority to regulate any subsurface injection of waste through underground injection wells (SDWA, Part C, Sections 1421-1426; U.S. EPA, 2003b). Underground injection is the technology of discharging fluids underground through any bored, drilled, or dug hole where the depth is greater than the largest surface dimension. In 1980, the EPA set regulations for the Underground Injection Control (UIC) Program, which established minimum requirements that states must meet in order to receive primary enforcement responsibility (primacy) of their state UIC program. Because Virginia currently does not have primacy, the EPA directly implements the UIC Program through a regional office in Philadelphia (U.S. EPA, 2003c).

In 1993, the Sierra Club filed a complaint against the EPA concerning its negligence in enforcing the SDWA regarding Class V underground injection wells (*Sierra Club v. Browner, D.D.C.*, Civil Action No. 93-2644 NHJ). Class V wells include “drainage wells used to drain surface fluid, primarily storm runoff, into a subsurface formation” (U.S. EPA, 2003c). The Sierra Club alleged that Class V wells have been known to inject substances that endanger drinking water sources, thereby violating the requirements of the SDWA. In 1997, a consent decree was issued requiring the EPA to complete a study of Class V injection wells. The results of this study were to provide the EPA background information to use in evaluating the risk that various types of Class V wells pose to underground sources of drinking water. In 1998, the EPA proposed an initial rule-making that increased regulations only for particular high-risk wells, and in 2001 issued a proposed determination maintaining that regulatory action for all other Class V wells was not necessary under Section 1421 of the SDWA (Underground Injection Control, 2001).

Although stormwater drainage wells (a type of Class V well) are not presently classified as high-risk wells, the EPA’s regulations for them nevertheless directly impact construction activities and reporting practices in karst areas. The primary types of stormwater drainage wells are bored wells, dug wells, and modified (“improved”) sinkholes. Sinkhole improvements include any modification intended to facilitate the drainage into karst features. The EPA regulates (i.e., requires registration and basic inventory information) the discharge of stormwater runoff into improved sinkholes (U.S. EPA, 2003c). In keeping with regulatory requirements, VDOT’s Location & Design Division joined with the Environmental Division and the Materials Division to implement guidelines (currently underway) for its construction projects that entail sinkhole improvements (VDOT, 2002). In addition, VDOT has committed to registering such discharges for the existing highway system.

As a result of the increased federal concern and attention toward groundwater pollution, considerable activity at the state level over the past 2 to 3 years has focused on the protection of karst groundwater. Highway runoff is often categorized with agricultural runoff and failing

septic systems as potential targets for additional controls. In Virginia, the Ground Water Protection Steering Committee (see Virginia DEQ, 1998) coordinates the state's groundwater protection activities. This interagency committee includes the DEQ, Virginia Department of Health, and DCR, among others. Urban runoff, including non-point source pollutants such as heavy metals (common constituents of highway runoff), is one of 10 sources of groundwater contaminants targeted as highest priority by the steering committee (Brown, 2001). Another state initiative targeting all sources of non-point source pollution was House Joint Resolution 161. This resolution tasked the State Water Commission to investigate and provide potential solutions to the problem of non-point source pollution in karst groundwater.

An additional statutory control over sinkhole discharges is the ESA, enforced by the U.S. Fish and Wildlife Service and the National Marine Fisheries Service. This act provides comprehensive control over activities that would threaten or endanger the habitats of federally listed species. The ESA makes it unlawful for anyone to "take" a listed animal, including significantly modifying its habitat (U.S. Fish and Wildlife Service, 2001). The ESA also affects regulation under the Clean Water Act. In 1999, a draft Memorandum of Agreement was published regarding enhanced coordination over the ESA and the Clean Water Act among the EPA, the Fish and Wildlife Service and the National Marine Fisheries Service (Draft Memorandum, 1999). For National Pollutant Discharge Elimination System permits (required for point sources that discharge pollution into U.S. waters) that have significant adverse effects on federally listed species or critical habitats, the EPA can work with the state to remove or reduce the adverse impacts of the permit. Therefore, although the regulations pursuant to the ESA do not specifically prohibit stormwater discharges to sinkholes, the EPA has the authority to prevent such discharges or to require monitoring or treatment if it is determined that a legitimate threat would be presented.

Highway Stormwater Runoff

Background

Numerous studies have investigated the constituents of highway runoff and the factors affecting its quality and quantity. The results of these studies vary greatly depending on a number of factors. These include traffic volume, surrounding land use, rainfall intensity and duration, length of dry period, operation and maintenance characteristics, degree of imperviousness of the drainage area, and ground slope (Helsel et al., 1979, Gupta, 1981). The "first flush effect," whereby concentrations of pollutants decrease with time during runoff events, also factors into the determination of runoff quality (Randall et al., 1978; Hewitt and Rashed, 1992).

Highway runoff may contain constituents including metals, solids, nutrients, bacteria, road salts, herbicides, and hydrocarbons such as fuel oils and gasoline (Latimer et al., 1990; Barrett et al., 1993). Rainfall has been reported as contributing up to 78% of the major ionic contaminants leaving the road surface in runoff and up to 48% of the suspended solids. Dustfall loadings, higher near urban areas, can also contribute a large fraction of the components in highway runoff (Barrett et al., 1993). Pollutant concentrations in the dissolved and suspended

solids in runoff are highly variable. Dissolved solids may contain potential contaminants. Suspended solids may reduce water clarity in receiving waters and may act as a substrate on which toxic materials may be absorbed, transported, and released into receiving waters (McKenzie and Irwin, 1983).

Vehicles have been found to be the major source of heavy metal deposition on road surfaces (Bourcier and Hinden, 1979). Iron, zinc, chromium, copper, lead, and nickel are often the most common metals in highway runoff (Wanielista et al., 1980). Heavy metal concentrations have been found to increase with impervious area and ground slope and in urban and industrial areas (Helsel et al., 1979).

Sedimentation and filtration process are valuable practices for removing the majority of the metals that pose the highest environmental concern in terms of groundwater pollution. Wet detention ponds are among the most common BMPs for the control of stormwater runoff and can be very effective in controlling a wide range of pollutants. Heavy metals in highway runoff concentrate in the bottom sediments of ponds, which have a great capacity to retain heavy metals (Yousef and Yu, 1992; Pitt et al., 1994). Another stormwater detention method, though not widely practiced, involves the diversion of highway runoff into wetlands. With this method, runoff constituent concentrations have been found to decrease greatly from the wetland's inlet to the outlet (Schiffer, 1988).

Impacts of Highway Runoff on Water Quality

Stormwater runoff from urban areas, including runoff from highways and other roadways, has been recognized as a source of contamination to receiving surface and groundwater bodies (U.S. EPA, 1984). Contaminants found in water bodies are often the products of varying land use activities. Agricultural pollution, acid rain, industrial pollution, and stormwater runoff are a few of the pollutant contributors that commonly reach water bodies. Many studies have addressed the levels and effects of contaminants in water bodies, but often the difficulty lies in determining the specific quantities associated with the source of contamination.

Processes in the soil, such as precipitation and adsorption, minimize the effects of runoff on groundwater. Though some constituents of highway runoff are more immobilized by soils than are others, attenuation through soils has an important effect on reducing contaminants that enter a water system (Yousef et al., 1984). Several studies have found that natural processes in the soil attenuate contaminants in highway runoff before reaching the aquifer (Bell and Wanielista, 1979; Waller et al., 1984; Barrett et al., 1993). Even with attenuation, however, many studies have found elevated levels of metal concentrations in groundwater that is in the vicinity of highways and runoff structures (Laxen and Harrison, 1977; Howie and Waller, 1986; Barrett et al., 1993).

Pollutant concentrations in receiving waters are highly variable among studies. For water bodies that are the recipients of runoff contaminants, several factors determine the extent of and importance of their effects. These include the size and type of the catchment area, the potential for dispersion, and the biological diversity of the water ecosystem (Barrett et al., 1993).

Highway deicing salts have often been identified as a seasonal constituent of highway runoff. Along highway edges, most of the salt that percolates downward with groundwater recharge has been found to enter the ground within 30 feet (Toler and Pollack, 1973). Hoffman et al. (1981) analyzed the effect of sodium chloride on lakes, streams, and rivers following deicing salt applications to highways above the water. They found elevated levels of chloride in streams and small lakes below heavily salted major freeways during the winter, quickly followed by decreasing chloride concentrations once salt applications decreased in the spring. In some studies, chloride from deicing salts is the only highway runoff constituent mentioned in the literature as potentially problematic. Peters and Turk (1981) conducted a study comparing major ion concentrations before and after a period of major highway development. They did not find statistically significant increases in all major ions except sodium and chloride, due to deicing salts. Sodium and chloride levels did not, however, exceed the upper limits of the public health standards. Ku and Simmons (1986) measured concentrations of pollutants in groundwater receiving stormwater runoff from a major highway and other paved areas. They found that concentrations of most measured constituents were within federal and state drinking water standards; an exception was from deicing salt in parking lot runoff in the winter.

Without strict adherence to BMPs, highway construction has been shown to have a pronounced effect on water bodies. Highway construction can particularly affect the erosional processes in a watershed. The extent of the impact depends on factors such as climate, soil characteristics, vegetation, geomorphology, and construction methods. Despite the use of erosion control methods, highway construction has resulted in increased turbidity, suspended solids, total phosphorus, and dissolved silicon in downstream waters (Burton et al., 1976, Kayhanian et al., 2001).

Impacts of Highway Runoff on Aquatic Organisms

Many studies have assessed the impact of undiluted highway runoff on various aquatic organisms. Gjessing et al. (1984a) conducted toxicity tests of several organic highway runoff micropollutants on salmon, algae, bacteria, fungi, and fish eggs. None of these tests suggested any negative effect on growth or behavior, though the study emphasized the importance of evaluating the bioaccumulation potential and chronic effects. Lord (1987) studied the effect of undiluted highway stormwater runoff on species of fish, isopods, algae, and amphipods. Runoff was not lethal to any of the organisms tested, though there were adverse effects on algal growth resulting from the interaction among the various runoff constituents. Barrett et al. (1993) also found adverse effects to algae and zooplankton as a result of exposure to soluble pollutants in highway runoff.

Some studies have reported higher concentrations of contaminants in aquatic biota than in water samples. Mathis and Cummings (1973) found that concentrations of copper, nickel, lead, chromium, lithium, and zinc were lowest in water samples taken from the Illinois River, increased through clams and fish, and the concentrations were highest in worms. In a creek in Illinois, concentrations of the metals cadmium and lead were also lowest in water samples, and higher concentrations occurred in biota and sediment (Williams et al., 1973). Highway runoff

was not the only source of pollutants in these studies, however, and the quantities associated with each source of contamination are unknown.

Highway construction, particularly instances when BMPs are improperly employed, can have a more evident and devastating effect on aquatic animals. Improper highway construction practices created repeated episodes of muddy water in karst springs, which caused a large trout die off due to clogged fish gills (Werner, 1983). Construction of an interstate in West Virginia resulted in large quantities of silt and clay washing into a system of caverns, resulting in a large trout kill due to silt build-up on their gills. Spilled diesel fuel on the construction site poisoned other fish (Garton, 1977).

Buckler and Granato (2002) reviewed 44 reports on the biological effects of highway runoff on local ecosystems and found conflicting results depending on the methodology. Their literature review indicated that highway runoff constituents are often found in tissue samples of aquatic biota that inhabit receiving waters near a highway. In these studies it was generally agreed that the presence of these contaminants might affect the diversity and productivity of biological communities. However, a methodology that employs bioassays (whereby contaminant sensitivity is tested by exposing organisms to toxins) suggested that highway runoff is not toxic to aquatic biota.

Highway Runoff in Karst Areas

Natural filtration through soil is nearly or completely nonexistent in karst areas. Karst aquifers are therefore among the most highly vulnerable to contamination. The quality of groundwater in karst aquifers can vary according to the lithology of rocks. The mineralogy of Virginia's limestone karst terrain should therefore be a consideration when the impurities of groundwater are evaluated. Many determinants of water quality, such as calcium, magnesium, sodium, potassium, and chloride, are naturally higher in groundwater from shales and limestones (Singh and Dubey, 2001).

Although there is an abundance of literature concerning karst groundwater quality, relatively little research has been conducted addressing the specific impacts of highway runoff to groundwater in karst areas. Studies evaluating highway runoff that directly enters a water body without first leaching through soil are somewhat comparable to studies evaluating highway runoff in karst areas. Gjessing et al. (1984b) analyzed samples from a lake used for drinking water into which highway runoff is pumped untreated. The water satisfied drinking water standards but was significantly affected by chlorides from the road salt. Wanielista et al. (1980) evaluated the effects of highway bridge runoff on adjacent water bodies in Florida. Lead was the only metal analyzed in lake water samples to exceed maximum permissible concentrations recommended by the state regulatory agency. Boating activities in the lake were identified as an additional source of lead contamination.

Quantifying the degree of dilution of contaminants from highway runoff alone can be difficult to assess or predict accurately. Using runoff-contaminant concentrations and loadings, mathematical formulae and models have been developed to address this issue (Bourcier and

Hinden, 1979; Bourcier and Sharma, 1980). Despite numerous studies on the topic, the full significance of intermittent discharge of highway runoff on the quality of receiving waters is not well documented (Dupuis et al., 1999). The multitude of parameters that must be considered creates difficulty in applying one study to various scenarios. For instance, factors such as the concentration of contaminants, the size and type of the water body, and the potential for dispersion are a few of the numerous variables needed to predict the degree of dilution that occurs in a water system. Wanielista et al. (1980) compared the total concentrations of heavy metals in bridge runoff to the concentrations of those metals in the runoff of the receiving lake below. The total concentrations of zinc, lead, nickel, and iron from the bridge averaged 4.7, 20.8, 3.5, and 12.6 times higher, respectively, than those concentrations in the lake. These values would be even higher excluding the contaminant inputs from other pollutional sources. Most aquifers have been impacted by more than one land use activity. Assessing the impacts of highway runoff on groundwater quality is complicated by these other contaminant sources. Hoos (1988) evaluated the effect of stormwater runoff on the quality of local groundwater in urban karst terrain. Concentrations and loads of most major constituents were much smaller in stormwater runoff samples taken from a drainage well than in the discharge of a spring, suggesting that other pollution sources contribute contaminants to the groundwater.

Despite the frequent grouping of highway runoff and numerous pollution sources as targets for control by regulatory agencies, research indicates that agriculture and industry are the most significant sources of groundwater pollution in karst areas. Livestock and crop production, in particular, are often singled out as significant contributors to groundwater protection in karst aquifers (Reeder and Day, 1993; Currens, 2001; Singh and Dubey, 2001). Garcia (1992) investigated the quality of stormwater runoff and its potential effect on groundwater quality in three watersheds in the karst terrain of Elizabethtown, Kentucky. This area has become a center of industrial and commercial growth, and its watersheds are hydraulically connected to municipal supply wells and springs. Although agricultural practices and industrialization contributed high levels of bacteria, herbicides, and tetrachloroethylene (a common degreasing and dry-cleaning solvent), concentrations of metals associated with roadside deposition were well below maximum contaminant levels (MCLs) and secondary MCLs established by the EPA (U.S. EPA, 2003d).

Table 1 presents 10 studies that have assessed groundwater quality in karst areas. This table, originally created by Stephenson and Beck (1995), was altered for comparison with MCLs of the National Primary and Secondary Drinking Water Standards established by the EPA (U.S. EPA, 2003d) and administered by DEQ. The values were collected under different protocols and should not be used for regional or temporal comparisons (Stephenson and Beck, 1995). Only contaminants listed in the Primary or Secondary Drinking Water Standards were taken from the original table. Of the 11 contaminants, 9 of the 31 values have ranges with portions that exceed the MCLs. Nitrate makes up the majority of these 9 values. Nitrate is primarily derived from nitrification of ammonium in the soil, commonly produced from cultivation or application of manure to fields (Kozar and Mathes, 2001). Leaching of fertilizer nitrogen, municipal and industrial wastewater, animal feedlots, refuse dumps, and urban drainage are other probable causes of nitrate contamination in drinking water (Vanden Heuvel et al., 1992; Katz and Hornsby, 1998).

Table 1. Summary of Literature Values From Karst Groundwater Studies, as Originally Provided in Stephenson and Beck (1995)

	Maximum Contaminant Level (mg/L)	Concentrations by Data Source (mg/L)									
		1	2	3	4	5	6	7	8	9	10
Total Dissolved Solids	500		72-410								
Nitrate	10	0-267 (7.4)	8.33-16.26	0.7-2.9	10.5-16.6	0-2.2	0.02-31	0.05-4.1	1.8-14.7	0.3-3.0	3.16
Sulfate	250	0-0.0-129.1 (27.5)			10.4-27.1	1-29		4.4-32.4		10-26	
Chloride*	250	0.4-204 (19.5)	52.5		4.0-10.0	1-33		3.9-48	4.9-62.2	7-28	13.1
Cadmium	0.005			0.012-0.02							
Chromium	0.10			0.08-0.10 ^a							
Copper	1.3			0.1-0.19							
Iron*	0.3			1.05-2.2							
Lead	0.015			< 0.5							
Silver*	0.1			0.05-0.19							
Nickel	0.61 ^b			0.07-0.12							

1 Bradbury and Muldoon (1992): Wisconsin, range of values (and mean value) from domestic wells, monitoring wells, piezometers, and springs.

2 Brown, and Ewers (1991): Kentucky, values from a well.

3 Reeder and Crawford (1989): Kentucky, approximate range of means from wells, caves, and springs.

4 Kastrinos and White (1986): Pennsylvania, range of means from conduit-flow springs.

5 Meiman (1990): Kentucky, approximate range of means from springs and surface water.

6 Ogden et al. (1991): Tennessee, range of values from wells and springs.

7 Pride et al. (1988): Tennessee, range of values from springs and sinkholes.

8 Reeder and Day (1993): Wisconsin, range of values from wells, caves, and springs.

9 Rothermal and Ogden (1986): Texas, range of values from a conduit-flow spring.

10 Wiersma et al. (1984): Wisconsin, mean values from a complex of springs.

^aValue provided in DEQ's drinking water standards only; nickel is not listed in EPA's Drinking Water Standards.

^bSamples include both trivalent chromium (non-toxic) and hexavalent chromium (regulated by the EPA).

The table was altered for comparison with maximum contaminant levels (MCLs) established by the Environmental Protection Agency (EPA) and used by Virginia Department of Environmental Quality (DEQ). Only contaminants with MCLs listed in the EPA's National Primary (*or Secondary) Drinking Water Standards are shown. **Bold** values indicate that a portion of the range of contaminant levels exceed those set by the EPA and DEQ; see text for discussion of potential sources of contamination.

Reeder and Crawford (1989), represented in Table 1, found concentrations of other metals, including cadmium and lead, to exceed MCLs. These metals were potentially derived from various land use activities. For example, cadmium emissions to water arise from phosphate fertilizers, non-ferrous metals production, and the iron and steel industry (Van Assche and Ciarletta, 1992). Lead was phased out of gasoline in the United States in the mid 1980s; prior to

that, lead was contributed to the highway environment primarily from the combustion of leaded petrol (Laxen and Harrison, 1977). Although several earlier studies have linked highway runoff to increased levels of lead in nearby soil and groundwater (Howie and Waller 1986; Laxen and Harrison, 1977; Rickert et al., 1977), road and highway use is no longer the major contributor to lead pollution. Reeder and Crawford (1989) concluded that because of the dilution of contaminants from the entire groundwater basin under Bowling Green, Kentucky, the overall contamination from all pollutional sources was insubstantial.

Taking into consideration the contaminant inputs from other land use activities and the dilution of contaminants within an aquifer, the values in Table 1 indicate that highway runoff constituents are not significant pollutants in karst areas. Chloride levels, commonly mentioned as being seasonally elevated in receiving waters following deicing salt application, were also well below MCLs in the karst aquifers represented in these studies.

CONCLUSIONS

- *The literature suggests that highways are not major contributors of non-point source pollution of karst aquifers compared to other land uses.* Research has shown that obtaining quantitative evidence on the effects of highway runoff on receiving waters is difficult. Methods that are commonly employed frequently have limitations. Researchers often either analyze the constituents of highway runoff but are unable to quantify the diluting effects of the receiving water or assess quantities of pollutants in water samples but are unable to isolate the amounts contributed from each pollutional source. For studies that have found substantial quantities of pollutants in receiving waters, incorporating information on surrounding land use activities and their potential pollutant contributions to the aquifer has suggested that highways are relatively minor contributors.
- *Highway construction can have adverse effects on groundwater quality and aquatic organisms, particularly in karst areas when BMPs are not properly employed.* Prior to highway construction, dye-tracing studies have proven effective in providing hydrogeologic information on the functioning of karst aquifers and on the likely impacts from construction (Bednar and Aley, 2001). During construction, the use of runoff control devices and native vegetation along roadways has been successful in reducing water pollution from both point and non-point sources (Barrett et al., 1995). Because of the ease of groundwater contamination in karst areas, strict adherence to BMPs is of particular importance during highway construction.
- *Employing continued caution on the quantity and frequency of salt applications on roads in karst areas would benefit VDOT.* The impacts to groundwater from salt application has received much attention in the literature. Studies evaluating chloride levels in karst aquifers have indicated that MCLs were not exceeded. The significance of the impact of deicing salt use on plants and aquatic animals, however, remains unclear.

- *Some evidence suggests that the potential exists for impacts to aquatic biota from highway construction and operation (depending on species and circumstances). Future VDOT projects near karst features known to contain federally listed aquatic species may therefore be required by the EPA to take preventative measures. Although a good deal of research has evaluated the impacts of highway runoff on aquatic organisms, little has been done in karst areas specifically. Results of research on the biological effects of highway runoff in aquatic habitats vary depending on circumstances and methodology. This creates difficulty in making quantitative comparisons on which to base conclusions. More research that applies standard research methodology to karst ecosystems is necessary to understand the magnitude of effects to biota and to make conclusions on whether additional preventative measures during highway construction and operation are necessary.*
- *Although more research of karst groundwater contamination is needed, the literature does not currently support the potential implementation of more stringent reporting requirements or permitting obligations concerning highway construction and maintenance in Virginia's karst areas. Water quality decisions by regulatory agencies are based in part on results of regular monitoring and analyses of water samples relative to MCLs. Currently, the EPA and Virginia regulatory agencies do not require VDOT to take actions in karst areas beyond the use of BMPs and measures concerning the discharge of stormwater runoff into improved sinkholes.*

RECOMMENDATIONS

1. *VDOT should adhere strictly to the proper use of BMPs during highway construction in karst areas.*
2. *VDOT should employ continued caution in the quantity and frequency of salt applications on roads in karst areas.*
3. *VDOT should conduct more research that applies standard research methodology to karst ecosystems in order to understand the magnitude of effects to biota and to make conclusions on whether additional preventative measures during highway construction and operation are necessary.*

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